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Measurement and Data Distribution for Microgravity Accelerations on the International Space Station

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Abstract

Two accelerometer systems will be available on the International Space Station to support microgravity payloads with information about the quasi-steady and vibratory acceleration environment of the research facilities. The Microgravity Acceleration Measurement System will record contributions to the quasi-steady microgravity environment, including the influences of aerodynamic drag, vehicle rotation, and venting effects. The Space Acceleration Measurement System-II will measure vibratory disturbances on-board due to vehicle, crew, and equipment disturbances. Due to the dynamic nature of the microgravity environment and its potential to influence sensitive experiments, NASA's Principal Investigator Microgravity Services project has initiated a plan through which the data from these instruments will be distributed to researchers in a timely and meaningful fashion. Beyond the obvious benefit of correlation between accelerations and the scientific phenomena being studied, such information is also useful for hardware developers who can gain qualitative and quantitative feedback about their facility acceleration output to Station. Further, a general characterization of the Station microgravity environment will be obtained that affords scientists and hardware developers the pre-flight ability to anticipate the acceleration environment available for experimentation.

A standard suite of acceleration data displays will be available, including such fundamental displays as acceleration versus time and power spectral density options. Additionally, acceleration data will be processed into investigator-defined data displays that will be available to the science teams in a near real-time manner. Such displays will include standard or custom plots of acceleration data and more complex visuals involving ancillary International Space Station data.

To supplement the near real-time displays, planned information resources will also be provided throughout the tenure of the systems on Station. General characterizations of the environment as it evolves will be made available on a regular basis so that investigators are aware of the overall environment in which their experiments were conducted. Accelerometer data archives and automated data analysis servers will allow investigators the ability to request customized data analysis support.

Acronyms

AOS	Acquisition of Signal
EE	Electronics Enclosure
GSE	Ground Support Equipment
HDF	Hierarchical Data Format
ISS	International Space Station
LOS	Loss of Signal
MAMS	Microgravity Acceleration Measurement System
MESA	Miniature Electrostatic Accelerometer
OARE	Orbital Acceleration Research Experiment
PI	Principal Investigator
PIMS	Principal Investigator Microgravity Services
RTS	Remote Triaxial Sensor System
SAMS	Space Acceleration Measurement System
SAMS-II	Space Acceleration Measurement System-II
SE	Sensor Enclosure
SOFBALL	Structure of Flame Balls at Low Lewis Numbers
STS	Space Transportation System
TSC	Telescience Support Center
WWW	World Wide Web

Introduction

The NASA Glenn Research Center (GRC) Principal Investigator Microgravity Services (PIMS) project supports NASA's Microgravity Research Division Principal Investigators (PIs) by providing acceleration data analysis and interpretation for a variety of microgravity carriers including the International Space Station (ISS), the Space Shuttle, the Russian Mir Space Station, parabolic aircraft, sounding rockets, and drop towers. The PIMS project is funded by the NASA Headquarters Office of Life Sciences and Microgravity Applications (OLSMA) and is part of the NASA Glenn Research Center's Microgravity Measurement and Analysis Project (MMAP) which integrates the analysis and interpretation component of PIMS with the various NASA sponsored acceleration measurement systems.

In general, the PIMS project's acceleration data support efforts are to archive and disseminate accelerometer data. PIMS supports users of microgravity platforms by identifying microgravity acceleration disturbance sources related to vehicle systems, experiment hardware, and other systems. The identification of microgravity acceleration disturbance sources is useful to PIs whose experiments were exposed to the disturbances as well as to future PIs who need to understand the microgravity environment under which their experiment will ultimately operate. The design of data analysis techniques[1] and the creation of displays per user requirements further enhance an investigator's ability to understand the results of their experiment. PIMS continually strives to educate users about the microgravity environment and available data analysis techniques. PIMS has conducted these characterization efforts in support of PIs conducting experiments on parabolic aircraft, sounding rockets, the Russian Mir Space Station, and the Space Shuttle. This effort will continue during PIMS characterization of the microgravity environment of the ISS.

International Space Station Acceleration Measurement Systems

The ISS microgravity acceleration environment consists of two regimes: the quasi-steady environment and the vibratory environment; therefore, the measurement of the microgravity acceleration environment on the ISS requires two accelerometer systems. For the ISS, the measurement of these two regimes is accomplished by the Space Acceleration Measurement System-II (SAMS-II) and the Microgravity Acceleration Measurement System (MAMS). The vibratory environment, consisting of vehicle, crew, and equipment disturbances and covering the frequency range 0.01 – 300 Hz, will be measured by the SAMS-II. Due to the localized nature of these vibrations, this frequency range requires measurement of the environment near the experiment hardware of interest. SAMS-II provides this distributed measurement system through the use of Remote Triaxial Sensor systems (RTS). An individual RTS consists of an Electronics Enclosure (EE) and two Sensor Enclosures (SE). An Interim Control Unit (ICU) housed in an International Subrack Interface Standard (ISIS) drawer collects data from all active EE's and prepares the data for downlink. For initial ISS operations, three EE's and five SE's will be available for vibratory acceleration environment measurement.

The MAMS will record the quasi-steady microgravity environment (f < 0.01 Hz), including the influences of aerodynamic drag, vehicle rotation, and venting effects. The MAMS unit will be located in the United States Laboratory Module in a double mid-deck locker enclosure. While MAMS contains accelerometers capable of measuring both the vibratory (MAMS High Resolution Accelerometer Package (HiRAP)) and quasi-steady (MAMS Miniature Electro-Static Accelerometer (MESA)) acceleration regimes, PIMS will utilize MAMS primarily for its ability to sense the quasi-steady regime. The MESA sensor is a flight spare from the Orbital Acceleration Research Experiment (OARE) program that was used to characterize the quasi-steady acceleration environment of the Space Shuttle Columbia. Like the OARE data recorded during eleven Space Transportation System (STS) missions, utilizing rigid body assumptions at these low frequencies will allow MAMS MESA data to be mapped to alternate locations within the ISS using ISS body rates and body angles data.

Basic Operational Philosophy

The PIMS operational philosophy for handling both MAMS MESA and SAMS-II data during ISS operations must address several operational challenges. Due to the anticipated Acquisition of Signal (AOS)/Loss of Signal (LOS) profiles, a means must be provided to merge the AOS and LOS data streams. The long operational period for the acceleration measurement systems requires the ability to accommodate a large volume of data arriving in a nearly continuous fashion. Finally, each SAMS-II accelerometer will not always be actively acquiring and transmitting data. As a result, a varying active accelerometer configuration profile is created. The sections that follow will address these challenges through real-time operations, near real-time operations, and offline data access.

As previously mentioned, both MAMS and SAMS-II are anticipated to be operational throughout the life of the ISS program. As a result, the underlying operational philosophy needs to address basic, core functions while allowing flexibility to address needs that develop over the course of operations. With this issue in mind, a core set of functions and capabilities are in development. These core capabilities are based on operational experience acquired by PIMS during real-time and offline operations with STS acceleration data acquired by the Space Acceleration Measurement System (SAMS) and the OARE and with Mir acceleration data acquired by SAMS. Additional capabilities will be added on an increment to increment basis as required. The origin of such additional requirements will be PI specific needs not addressed by the core functions and operational enhancements identified by PIMS during the course of operations.

PIMS will store acceleration data in both processed form and raw packet form. Only the processed acceleration data files will be available to investigators for direct access. The user-friendly directory hierarchy shown in Figure 1 has been developed to simplify access to the processed acceleration data. The PIMS offline operations center around the need to characterize the microgravity acceleration environment for PIs conducting experiments on board the ISS. Offline operations address two primary functions served by PIMS. First, PIs require analysis and interpretation of the measured environment in direct support of their science measurements. Time domain and frequency domain analysis conducted on the acceleration data can assist the PI in understanding the environment under which their experiment was conducted. The second function addresses the need to conduct a general characterization of the microgravity environment in anticipation of future investigators. For the vibratory environment, obtaining such a general characterization requires access to acceleration measurements distributed throughout the ISS.

Real-Time Operations

The crux of PIMS real-time operations involves the routing of SAMS-II and MAMS acceleration data from on board the ISS to PIMS Ground Support Equipment (GSE) located at the NASA Glenn Research Center's Telescience Support Center (TSC) as shown in Figure 2. On arrival of the acceleration data at the TSC, the PIMS GSE must provide the means to receive, process, display, and archive this acceleration data. The display and archive functions will be discussed separately here, but operationally will occur in parallel.

PIMS GSE located at the TSC will be capable of generating a standard suite of acceleration data displays, including various time domain and frequency domain options. These data displays will be updated in real-time and will periodically update images available via the PIMS web page. The planned update rate is every two minutes.

Upon receipt of the various acceleration data packets, the PIMS GSE will write the packets into a database containing two columns: time information extracted from the packets and the entire as-received packet itself. A separate database will be generated for each active accelerometer from each accelerometer system. Display processing software will access a given accelerometer's database and perform the requested processing for that accelerometer. Since the individual triaxial accelerometers are controlled by PIs, the processing performed on a given accelerometer's data will be driven primarily by PI requirements. In order to perform real-time analysis of the data, processing of a given accelerometer's data may also be influenced by PIMS requirements. PIMS GSE will be capable of generating a standard suite of acceleration data displays including the time domain and frequency domain options identified in Table 1 and Table 2. In general, no frequency domain analysis is performed on the quasi-steady acceleration data. However, the time domain techniques listed in Table 1 identify the time domain processing options for quasi-steady and vibratory acceleration data.

The displays generated by the PIMS GSE will be updated in real-time as new packets are received and inserted into the real-time database. Periodically, electronic snapshots of the displayed images will be obtained by the display software and those images will be routed to the PIMS World Wide Web (WWW) page for viewing by interested PIs. The PIMS WWW page will provide access to the acceleration displays for all active accelerometers.

Figures 3, 4, and 5 offer examples of acceleration data plots generated by PIMS GSE from various STS missions. Figure 3 is a cumulative Root-Mean-Square (RMS) acceleration versus frequency plot using SAMS data from the third United States Microgravity Payload (USMP-3) mission (STS-75). The two traces on the plot depict a crew exercise period and a non-crew exercise period and clearly illustrate the effects of exercise on the microgravity environment.

Figure 4 is a color spectrogram that provides a Power Spectral Density (PSD) versus time versus frequency representation of six hours of data from the Life and Microgravity Spacelab (LMS) mission (STS-78). In general, the color spectrogram is used to provide a clear indication of start/stop events and clearly illustrate the frequency of various disturbance sources in the overall microgravity environment. For Figure 4, the repeated traces in the 22 Hz range represent the on/off cycling of refrigerators used to support the LMS experiments. Four exercise events and their corresponding excitation of the Orbiter structural modes are present in the 1-3 Hz range.

Figure 5 is a plot illustrating the relationship between raw OARE data and radiometry data from the Structure of Flame Balls at Low Lewis Numbers (SOFBALL) experiment. This clear relationship between the microgravity acceleration environment and SOFBALL experiment data demonstrates the primary reason PIMS provides its service. Based on correlation between radiometry data and OARE acceleration data, the SOFBALL experiment team was able to maximize their science by making adjustments to their experiment operating plan during the MSL-1 mission (STS-94).

Near Real-Time Operations

The primary function of the near real-time operations involves receiving acceleration data from LOS periods and generating processed data files for use in the PIMS offline processing system or for use by PIs at their local offline processing equipment. Upon receipt by the PIMS GSE, LOS acceleration data packets will be inserted in the real-time database, where they are effectively merged with AOS acceleration data packets. Overlap between AOS and LOS packets will be addressed by the removal of any such redundant packets upon insertion into the database. The resultant data set represents time ordered data with redundant packets removed.

For a given time period, after all AOS and LOS data packets have been received and inserted into the database, the Hierarchical Data Format (HDF) processor initiates its operations. HDF was developed by the National Center for Supercomputing Applications (NCSA) and is used by various scientific projects, including NASA's Mission to Planet Earth. For PIMS, the genesis of using the HDF standard involved lessons learned from STS operations, where many accelerometer data systems were utilized to characterize the microgravity environment. These various accelerometer data systems include NASA's SAMS and the OARE, ESA's Microgravity Measurement Assembly (MMA), ESA's Accelerometre Spatiale Triaxiale Electrostatique (ASTRE), and DLR's Quasi-Steady Acceleration Measurement (QSAM). The raw data and the processed data obtained from these multiple accelerometer system were stored in differing file formats, resulting in unnecessary difficulties regarding analysis of data from these accelerometer systems. Further, data comparison between systems was made unintentionally complicated. The ubiquity afforded by a universal file format allows PIs straightforward access to pertinent microgravity acceleration data, irrespective of the accelerometer system or its location within the ISS.

The HDF processor becomes active as required at fixed intervals throughout operations, operating on a fixed amount of data. The HDF processor returns to a dormant state after converting the raw packet data into HDF format data. As an example, the current estimate to insure all AOS and LOS data have been received is twelve hours. The HDF processor is scheduled to become active every thirty minutes. Stated more directly, after twelve hours it is assumed all AOS and LOS data for a particular accelerometer system have been transmitted through the system. PIMS experience with STS operations indicates this should be an adequate time period. At this twelve-hour point, the HDF processor converts the oldest thirty minutes of data currently available in the database to HDF format. The thirty minutes of data just converted to HDF format are subsequently removed from the database and the HDF processor again becomes dormant, waiting for the next thirty minute time interval to be reached.

An additional excellent feature of the HDF data file format allows storage of acceleration data and ancillary data together in a single file, greatly simplifying the offline processing of the data. The ancillary data describes the conditions and circumstances under which the acceleration data were obtained. The following items represent the current list of ancillary data parameters to be stored by PIMS in each processed data file: t-zero, t-end, sampling rate, cutoff frequency, head ID, gain, ISS CG, station configuration, location, orientation, coordinate system, bias coefficients, scale factor, and data quality measure. A change in any of these ancillary parameters results in the current file closing and a new data file being opened. Consequently, the ancillary data in each resultant file is representative of each data point within the file.

Offline Data Access Operations

In addition to the real-time processing of acceleration data and the generation of HDF files, the processed acceleration data will be archived and available for offline processing. The analysis options listed in Table 1 and Table 2 are similarly available for offline analysis of SAMS-II and MAMS data. As part of the PIMS microgravity environment characterization effort, PIMS data analysts will extract information from the acceleration data during offline operations. Processing time and resources for offline operations are not time-critical and therefore afford more detailed analysis of the acceleration data. The salient features of the ISS microgravity environment will be summarized in summary reports similar to those generated during STS operations.[2,3,4] These summary reports will be generated on an increment-to-increment basis in an effort to educate upcoming PIs about the ISS microgravity environment.

In addition to the data analysis conducted by PIMS, PIs can make requests for analysis directly through PIMS or through the PIMS analysis request form available through the PIMS WWW page. Table 1 and Table 2 list the standard time domain and frequency domain plot options available to investigators. The analysis will performed by PIMS analysts or will be performed automatically by PIMS offline processing software. Additionally, since the processed acceleration data will reside on a PIMS data file server, direct access to the processed data will be available through anonymous File Transfer Protocol (FTP). The user-friendly directory structure described previously in Figure 1 will simplify direct access to the processed files. Whether data plots or acceleration data file are requested, the resultant products will be made available to the investigator in a straightforward, timely manner.

Summary

The International Space Station provides a long duration experiment facility for microgravity science Principal Investigators. The Space Acceleration Measurement System-II and the Microgravity Acceleration Measurement System will accomplish measurement of the acceleration environment. The Principal Investigator Microgravity Services Project will provide analysis and interpretation of the ISS microgravity acceleration environment through real-time data processing and the generation of processed data files for post-experiment access by microgravity science Principal Investigators.

References

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[2] M. Moskowitz,K. Hrovat, P. Tschen, K. McPherson, M. Nati, T. Reckart, Summary Report of Mission Acceleration Measurements for MSL-1, NASA Technical Memorandum TM-1998-206979, May 1998

[3] M.J.B. Rogers, K. Hrovat, K. McPherson, R. DeLombard, T. Reckart, Summary Report of Mission Acceleration Measurements for STS-87, NASA Technical Memorandum TM-1999-208647, January, 1999

[4] K. Hrovat, K. McPherson, Summary Report of Mission Acceleration Measurements for STS-89, NASA Technical Memorandum TM-1999-209084, June, 1999

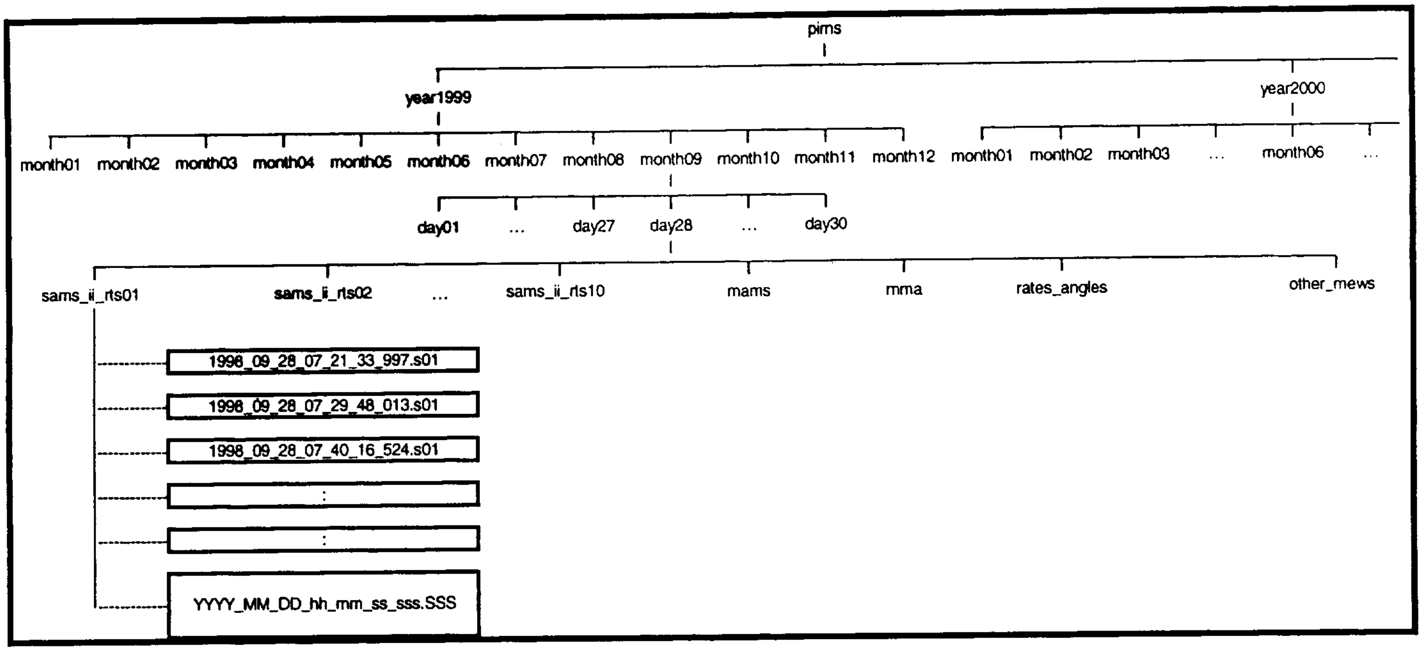

Figure 1 - PIMS Acceleration Data Directory Hierarchy

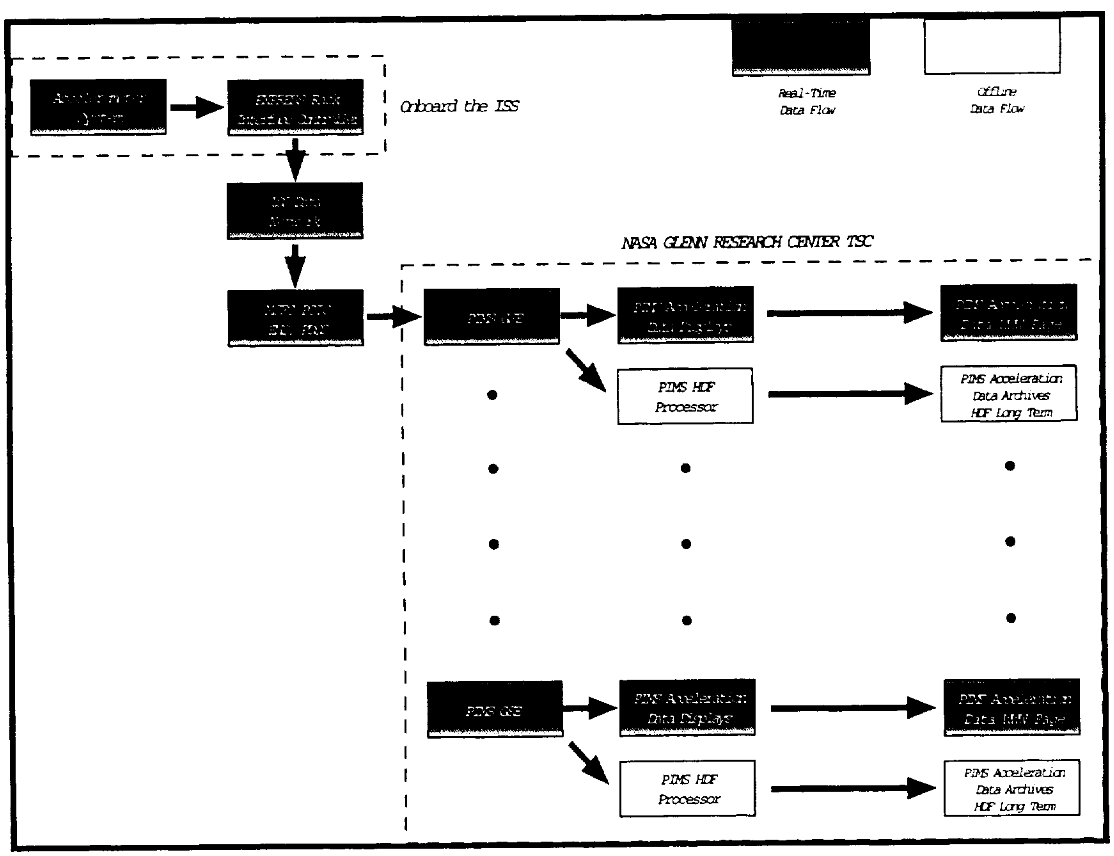

Figure 2 - Acceleration Data Flow

Display Format	Regime(s)	Notes
Acceleration vs. Time	Quasi-steady, Vibratory	• Precise accounting of measured data with respect to time; best temporal resolution
Interval Min/Max Acceleration vs. Time	Vibratory, Quasi-steady	• Displays upper and lower bounds of peak-to-peak excursions of measured data • Good display approximation for time histories on output devices with resolution insufficient to display all data in time frame of interest
Interval Average Acceleration vs. Time	Vibratory, Quasi-Steady	• Provides a measure of net acceleration of duration greater than or equal to interval parameter
Interval RMS Acceleration vs. Time	Vibratory	• Provides a measure of peak amplitude
Trimmed Mean Filtered Acceleration vs. Time	Quasi-steady	• Removes infrequent, large amplitude outlier data
Quasi-Steady Mapped Acceleration vs. Time	Quasi-steady	• Use rigid body assumption and using vehicle rates and angles to compute acceleration at any point in the vehicle

Table 1 - Time Domain Analysis Options

Display Format	Notes
Power Spectral Density vs. Frequency	• Displays distribution of power with respect to frequency
Spectrogram (PSD vs. Frequency vs. Time)	• Displays power spectral density variations with time • Identify structure and boundaries in time and frequency
Cumulative RMS Acceleration vs. Frequency	• Quantifies RMS contribution at and below a given frequency
Frequency Band(s) RMS Acceleration vs. Time	• Quantify RMS contribution over selected frequency band(s) as a function of time
RMS Acceleration vs. One-Third Frequency Bands	• Quantify RMS contribution over proportional frequency bands • Compare measured data to ISS vibratory requirements

Table 2 - Frequency Domain Analysis Options

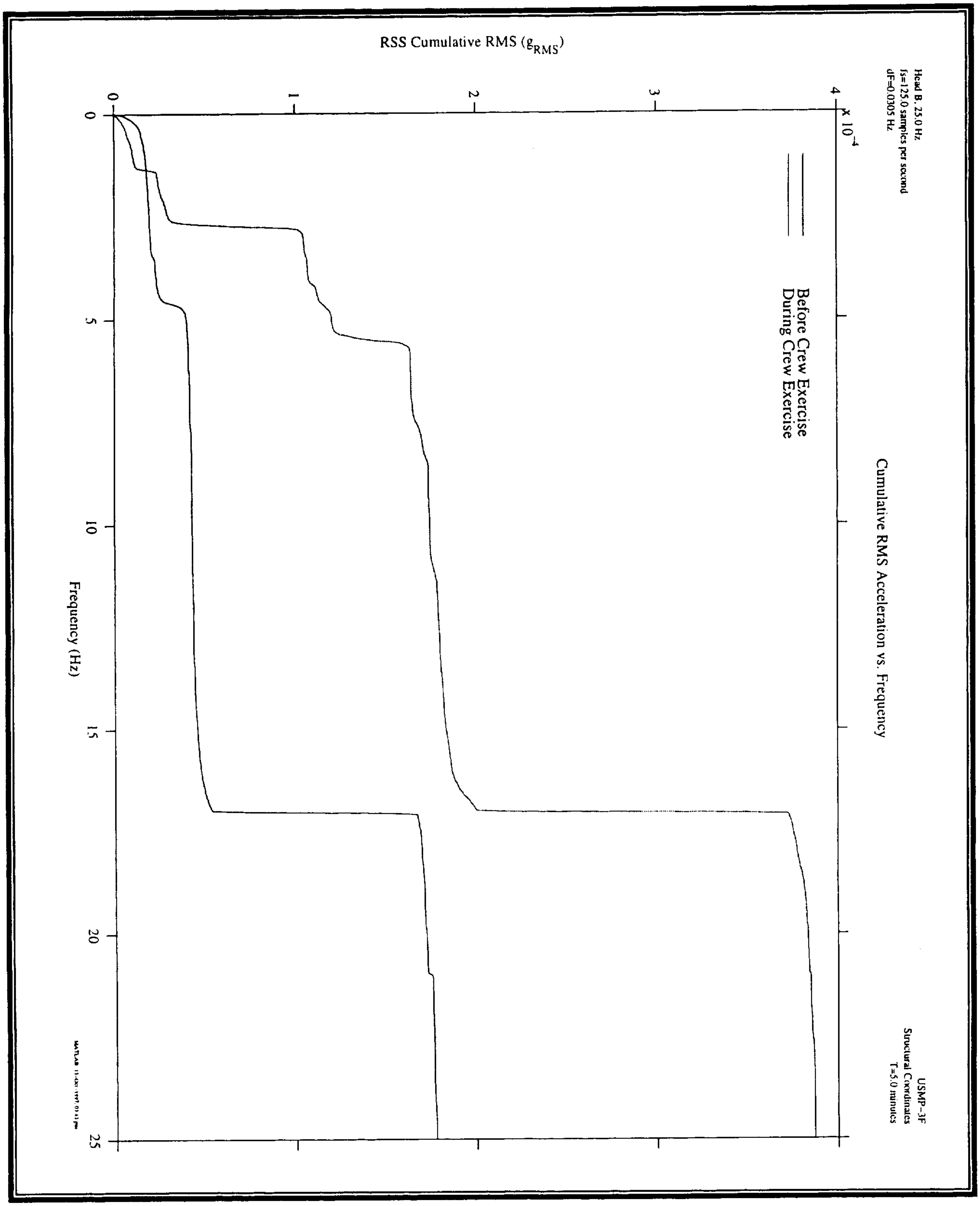

Figure 3 – USMP-3 Mission Cumulative RMS Acceleration Versus Frequency, SAMS Data

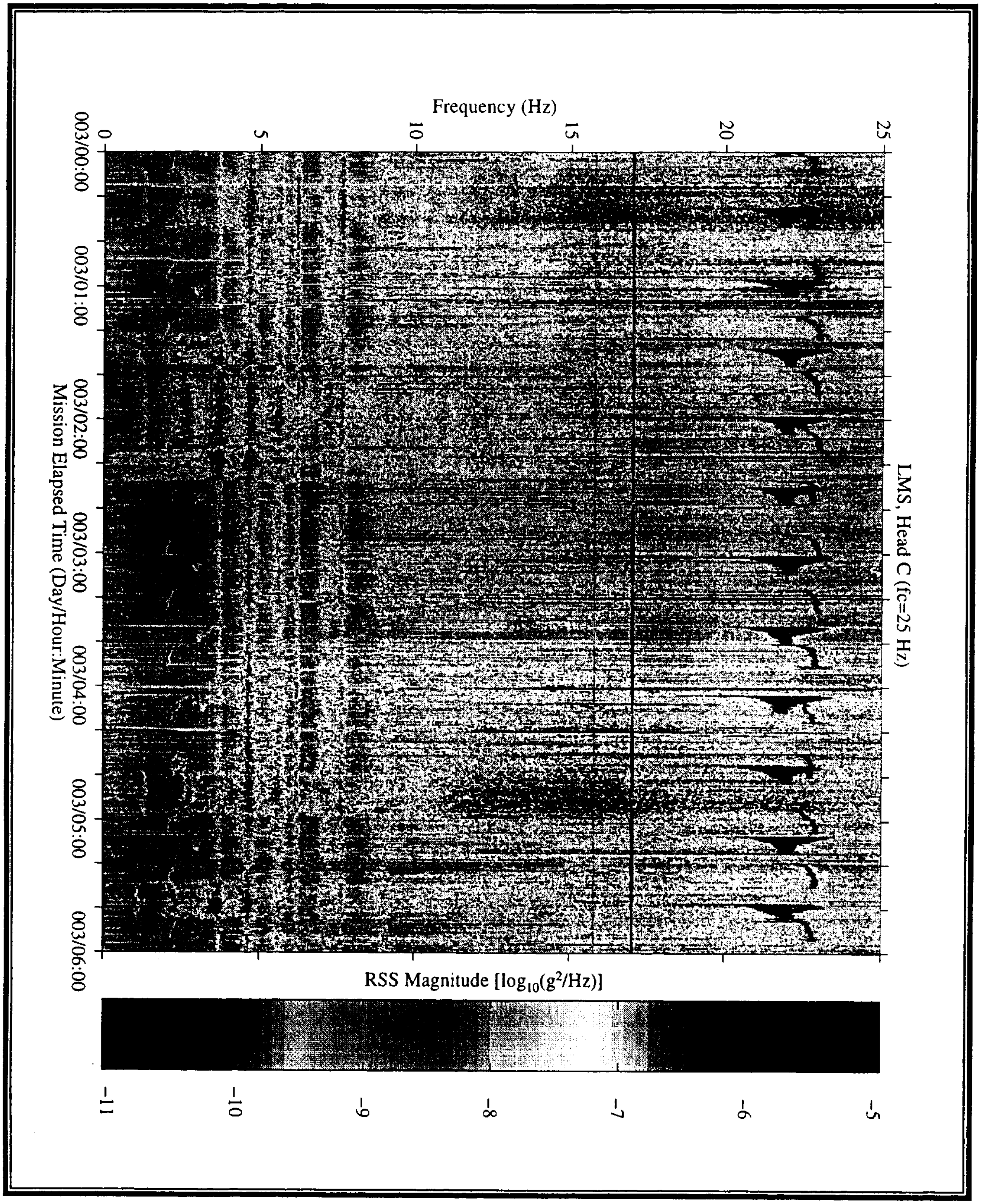

Figure 4 – LMS Mission Color Spectrogram, SAMS Data

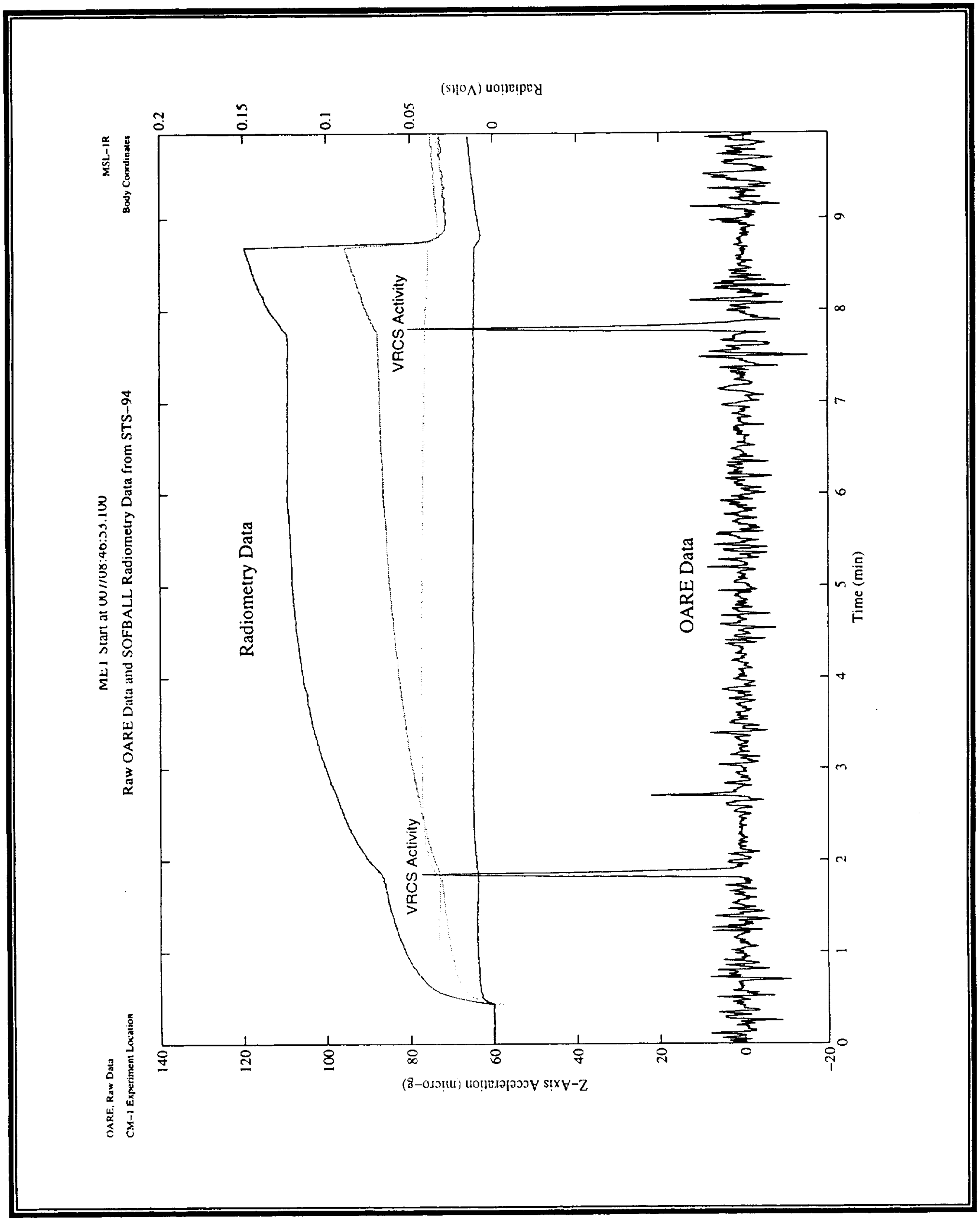

Figure 5 – MSL-1 Mission, SOFBALL Radiometry Data, Filtered OARE Data